A Thermometer for Interdependence: Exploring Patterns of Interdependence Using Networks of Affordances

Journal:	*International Conference on Information Systems 2015*
Manuscript ID:	ICIS-0065-2015.R1
Track:	18. Methodological and Philosophical Foundations of IS
Keywords:	Business process modeling, Interdependency, Networks

Abstract:	Interdependence is a central concept in systems and organizations, yet our methods for measuring it are not well developed. Here, we report on a novel method for transforming digital trace data into networks of events that can be used to visualize and measure interdependence. The edges in the network represent sequential flow and the vertices represent actors, actions and artifacts. We refer to this representation as an affordance network. As with conventional approaches such as process mining, our method uses input from a stream of time-stamped occurrences, but the representation is simpler and more appropriate for exploration and theory building. As digital trace data becomes more widely available, this method may become more useful in information systems research and practice. Like a thermometer, it helps us measure a basic property of a system that would otherwise be difficult to see.

A Thermometer for Interdependence: Exploring Patterns of Interdependence Using Networks of Affordances

Research-in-Progress

Brian T. Pentland
Michigan State University
East Lansing, MI 48824 USA
pentland@broad.msu.edu

Jan Recker
Queensland University of Technology
Brisbane, QLD 4001 Australia
j.recker@qut.edu.au

George Wyner
Boston College
Chestnut Hill, MA 02467 USA
george.wyner@bc.edu

Abstract

Interdependence is a central concept in systems and organizations, yet our methods for measuring it are not well developed. Here, we report on a novel method for transforming digital trace data into networks of events that can be used to visualize and measure interdependence. The edges in the network represent sequential flow and the vertices represent actors, actions and artifacts. We refer to this representation as an affordance network. As with conventional approaches such as process mining, our method uses input from a stream of time-stamped occurrences, but the representation is simpler and more appropriate for exploration and theory building. As digital trace data becomes more widely available, this method may become more useful in information systems research and practice. Like a thermometer, it helps us measure a basic property of a system that would otherwise be difficult to see.

Keywords: interdependence, affordance network, organizational routines, process mining, narrative network, exploratory data analysis

Introduction

Interdependence is a central issue in systems and organizations (Orlikowski 1992) and a defining feature of organizational routines (Feldman and Pentland 2003). Interdependence describes how actions, actors and technology in routines are intertwined in mutually dependent ensembles (Orlikowski and Scott 2008). Interdependence is like air; it surrounds everything in an organization, but it is difficult to see. Interdependence has been theorized to exist between organizational subunits (Thompson 1967), jobs (Kiggundu 1981), actions (Polyvyanyy et al. 2015), technologies (Leonardi 2011), but it is difficult to observe or measure (Wyner 2011). Thus, we aim to develop a method for observation and measurement of interdependence. Just as a thermometer allows us to record observations of temperature, we believe that it is important to develop new techniques for measuring and visualizing interdependence.

In this paper, we report research-in-progress on a tool for visualizing and measuring interdependence in what we call a network of affordances. So far, we have devised an algorithm for taking a stream of sequential, time-stamped occurrences and converting them into a network of interdependent events, much in the same way that existing technologies such as process mining (van der Aalst 2011b) operate. We have implemented this algorithm in a prototype software artifact, and we have examined data from an illustrative case of two organizational routines. The prototype provides an index of the overall level of interdependence in each routine.

Our contribution is both conceptual and methodological. *Conceptually*, we make two key moves. First, we describe events in terms of three dimensions: actors, actions, and artifacts. Together, these three ingredients make up the minimum required to describe an affordance (Chemero 2003). Affordances describe action possibilities that exist between an actor and a technological object, and they allow evaluating which action possibilities were actualized in routines. Thus, affordances allow description of *what someone* did with *something*. This is an important extension to other event networks, which typically focus on actors or artifacts but not the relationships between them (Pentland and Feldman 2008).

Second, we identify the sequential relationships between affordances as they are used in practice and construct a network based on these sequential relations. We use the term "affordance network" to describe this representation. This representation is similar to other event- (e.g., van der Aalst et al. 2004) or activity-based network models (e.g., Pentland et al. 2012), but it extends them by explicitly including actors, actions, as well as artifacts, all of which contribute to interdependence. This move also extends conceptualizations of affordances from a focus on technological objects themselves and the identification of one or more affordances (Leonardi 2011; Seidel et al. 2013) to the analysis of the sequences of events in which they are actualized. Importantly, this extension allows us to examine the interaction of actors and technological artifacts in a sociomaterial ensemble (Orlikowski 2007; Leonardi and Barley 2008), contributing a more nuanced view of the role of technology in routines. At this stage, our conceptual contribution is what Gregor (2006) would classify as a type 1 theory; it is limited to analysis and description. It offers a novel representation of work processes and routines. We provide an example of analysis involving the comparison of problem solving routines in a call center.

Methodologically, we offer a novel way to construct this kind of network from a stream of time-stamped occurrences. Traditionally, time-stamped occurrences are analyzed using process mining techniques, which construct state-transition graphs such as Petri nets (van der Aalst 1998). This analysis usually considers timestamps and activity events but largely ignores actors and artifacts let alone the relationships between them. Our algorithm explicitly includes these latter elements. We describe the algorithm, which is implemented in a prototype software artifact written in MATLAB. We are starting to see event-based networks used in information systems research (e.g., Goh et al. 2011). The method described here provides a rigorous, consistent foundation for building on that work.

We proceed as follows: Next we will describe the motivation for our research and position our affordance network within related work on interdependencies and approaches to modeling or analyzing organizational routines, and networks. Then we will provide a formal definition of an affordance network and briefly describe our implementation. We then present an illustration using data from routines observed in a US call center (Pentland 2003). We conclude by reviewing expected contributions, limitations and future work.

Related Work

Interdependence and its measurement

In theory, interdependence occurs between many kinds of entities, such as tasks (Arthur Jr. et al. 2005), actors (including roles, jobs, and organizational units, Thompson 1967) and technologies (Bailey et al. 2010). In practice, we see manifestations of interdependence primarily when there are breakdowns (Wyner 2011). When a process is running smoothly, it can be difficult to tell how the activities are related. When interdependencies become manifest, however, workarounds and other escalations are often required (Alter 2014). Managing interdependence is considered a critical aspect of organizational design in general (Thompson 1967) and information systems design in particular (Malone et al. 1999).

In research, interdependence is traditionally measured using perceptual survey measures (e.g., Campion et al. 1993; Arthur Jr. et al. 2005). The approach we describe here advances on this by using objective data (time-stamped digital "trace data") to infer sequential relationships between activities, actors and technological artifacts. We focus on sequential relationships for two reasons. First, sequential flow is a core issue in the design of information systems (Dumas et al. 2005). Second, Thompson (1967) described interdependence as a "Guttman scale", where sequential flow was the foundation. Higher levels of interdependence (pooled and reciprocal) are built on underlying flows. Subsequent frameworks (e.g., Malone et al. 1999) use the same basic idea: flow is the basic phenomenon. Interdependence can also be defined in terms of the economic payoff (Puranam et al. 2012), but our approach does not address that form of interdependence.

Approaches to modeling and analyzing organizational routines and processes

Our approach sets out to visualize and measure patterns of interdependence in routines of actors, actions and artifacts. Similar ambitions exist also in classical approaches to organizational analysis (Knights and Willmott 2010), most notably in approaches to business process management (vom Brocke and Rosemann 2010).

Process modeling is an approach often used by analysts to document and analyze current organizational operations, because these models help business personnel understand the work domain and identify improvement opportunities related to the routines and the involved information systems (Dean et al. 2001). Process models are a type of conceptual model, that is, they provide a typically graphical representation of some features of a real-world domain (Burton-Jones and Weber 2014) – the organizational routine the analyst is interested in. Process models are usually employed as part of an effort to analyze current operations ('as is' modeling), or as part of an effort to design improved blueprints for future operations ('to be' modeling). In either case, process models typically include graphical depictions of at least the process steps, agents, actors, roles and (sometimes) artifacts that are involved in a business process (Curtis et al. 1992). Importantly, process models are abstractions in that they describe largely the *common* way of how a routine *should* be enacted – to the point that escalations, workarounds or variations (that is, interdependencies) are deliberately excluded (Sharp and McDermott 2009). Also, in practice, any actor may choose to follow the modeled procedure but may also interpret and enact the procedure differently (Lee et al. 2008).

Process mining describes a technology-based methodology for process analysis that constructs Petri nets using data from event logs (van der Aalst et al. 2004) . Because they are able to model concurrency and system states, Petri nets provide a state-based framework for process representation (van der Aalst 1998). Current process mining research emphasizes the discovery of *accurate* models to allow for compliance checking and deviance analysis (van der Aalst 2011b) . Given appropriate data, it is possible to recover an accurate, detailed model for a digitized process at any given point in time. A common limitation of this approach, however, is that the mined models provide excruciatingly accurate, detailed information (so-called spaghetti models, see van der Aalst 2011a) such that pattern recognition or other analysis is often not possible without further transformation.

To explore and visualize patterns of interdependence, we argue that we need a model that does not abstract away variations as is typically the case with process models, and which allows views that do not always foreground the sequence of actions as is the case with both process models and process mining. Where actions are temporal in nature and thus evanescent, actors and artifacts are easier to observe and follow over time. By visualizing an organizational process as a network of affordances we hope to make visible aspects of interdependence that are more dependent on the relationships among actors and artifacts as well as actions.

Network models

We will define a network model, of which several kinds already exist. The most common are social networks (Borgatti et al. 2013), where the vertices represent individuals and the edges represent relations between the people, such as communications (Kossinets and Watts 2006), distance (Backstrom et al. 2010) or friendship ties (Ellison et al. 2007). Recently, scholars have extended the social network to include non-human entities (Kane and Alavi 2008), but the basic framework remains the same.

Of course, network models are widely applied to technical artifacts as well (Barabási and Albert 1999). Like social networks, the vertices represent discrete entities, such as web pages. So-called "actor-networks" (Latour 1987) can also be conceptualized as networks of artifacts, although research in this tradition does not typically employ mathematical network methods or models.

The most closely related work involves networks where the vertices represent actions or activities, rather than people or things. For example, Eppinger's (1991) design structure matrix is a network of activities or processes. Pentland and Feldman (2007) use the phrase "narrative network" to describe the same basic idea: a network where the vertices represent activities or events. Such event-based networks are becoming increasingly common in empirical research in information systems. For example, Goh et al. (2011) use narrative networks to identify where and how the introduction of health information technology changes sequences of actions in routines.. For Goh et al. (2011) an affordance is the confluence of an artifact and an actor. Such affordances are viewed as vital to, but distinct from the functional events which comprise a narrative network. Yeow and Faraj (2011) use narrative networks to investigate changes resulting from an ERP implementation. Pentland et al. (2010) used a network model to compare patterns of action generated by invoice processing systems. In research on healthcare information systems, Hayes et al. (2011) use action networks to study the impact of new technologies and potential needs for additional training at a medical center.

In summary, prior methods tend to highlight actions, people or technology, but not all three. Recent interest in socio-materiality (Orlikowski and Scott 2008; Leonardi 2013) has shown that these dimensions are tightly inter-related, but existing models generally pick out one or two dimensions, at most. Here, we introduce a representation where, all three dimensions are used to define each node in the network.

Definitions and Notation

We define an affordance network as a class of event network where the actor, action and artifacts are all available to identify the vertices of the network. The basic notation for event networks is summarized in Table 1 and explained below. The rightmost column of Table 1 provides illustrations taken from the empirical example discussed below.

On the basis of the event network notation, an affordance network can be constructed whenever the stream of occurrences contains the three basic dimensions: actor, action, and artifact. Thus, affordance networks are a subclass of event networks. It should be clear to readers who are familiar with the nuanced models of affordances (Chemero 2003) that we are using a simplified definition here. For instance, we do not examine affordances that exist as action possibilities but only those that are in fact *actualized* (e.g., Bernhard et al. 2013; Strong et al. 2014), that is, enacted by actors in their routines. Also, rather than focusing on relations *within* a particular affordance, we are using digital trace data to examine sequential relations *between* affordances as they are actualized in a given setting. These relations provide an indication of the pattern of interdependence in the setting. Thus, we do not consider potential or hidden affordances, only actualized ones, and how these actualizations are sequentially related in the data.

Occurrences. We define an occurrence-based data set as consisting of a set of occurrences, $\boldsymbol{\Omega} = \{ \omega_1, \dots , \omega_m \}$. The index i indicates the i_{th} occurrence in the stream of data. The occurrences can be sequentially ordered by time such that $t_i \leq t_{i+1}$, so that ω_i precedes $\omega_{i+1.}$

Occurrences are treated as instantaneous observations. Each occurrence has a timestamp and may have other data that records what occurred at that moment. Thus, each occurrence has a set of attributes such as the time, location and type of the occurrence. Attributes may also include actors, artifacts, text, or anything else. Each occurrence ω_i takes the form (t_i, y_i), where t_i is the time of the occurrence and y_i is a function from $\boldsymbol{A}$, the set of attributes being observed, to $\boldsymbol{O}$ the set of possible values for those attributes. Thus $y_i(a)$ is the value observed for attribute a in occurrence ω_i.

In practice, an occurrence-based data set can be stored in a simple spreadsheet, where each row is an occurrence. One column includes the timestamp and the other columns include the other attributes. For example, when actors are included in the attributes, it is possible to infer a social network (O'Madadhain et al 2005). When actors, actions, and artifacts are included, it is possible to construct a network of affordances.

Threads. Occurrences are often observed and recorded as coherent *threads*. A thread is a set of time-ordered occurrences that all pertain to a single coherent flow of action. Thus, any given thread, $\theta_{i,}$ is a subset of the overall set of occurrences: $\theta_i \subseteq \boldsymbol{\Omega}$. Within any thread, occurrences can be sequentially ordered. The thread is a central concept in this framework because it is used to define the edges of the event network. It is an indicator of what Abbott (1992) referred to as "colligation": the logical relationship of events.

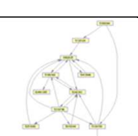
Events. Following Abbott (1992) and related literature, we distinguish between occurrences and events. Events are defined as the subset of occurrences ($\upsilon_i \subseteq \mathbf{\Omega}$) that have the same observed value for an attribute or set of attributes. For a set of attributes $\boldsymbol{B} \subseteq \boldsymbol{A}$, we can partition $\mathbf{\Omega}$ into a set of events υ_i over $\boldsymbol{B}$ such that every ω_i in $\mathbf{\Omega}$ is in exactly one such υ_i and for any ω_i and ω_j which are both in υ_i, $y_i[\boldsymbol{B}] = y_j[\boldsymbol{B}]$.

Occurrences are instantaneous, but events have duration, which can be computed as the difference in timestamp between the first and last occurrence in the event. While the distinction between occurrences and events may seem non-intuitive at first, it is an essential step in any rigorous analysis of sequential, historical data (Abbott 1992) or indeed processes (van der Aalst 2011b).

Event network. The event network is a valued, directed graph. In an event network, the set of events, **V**, form the vertices. The set of edges, **E**, is formed by following the threads. An edge ε_i exists between events υ_1 and υ_2 whenever there is a thread containing occurrences ω_j and ω_k that are sequential within the thread and where ω_j is in υ_1 and ω_k is in υ_2. Edges can be interpreted as indicators of sequential interdependence between two entities.

In an event network, the vertices represent events, and the edges represent the sequential interdependence between those events. Where a social network represents relationships between pairs of actors, an event network represents relationship between pairs of actions. It is important to emphasize that event networks are not multimodal (e.g., actors × event); they are unimodal (event × event). Because it only represents pairs of events, an event network cannot represent concurrency or higher-order sequences. Further, unlike a Petri net, it does not attempt to model the state of the underlying system.

Table 1: Essential concepts, definitions and notation

Concept	**Definition**	**Notation**	**Example**
Occurrences (**Ω**)	Each occurrence, ω_i, is an instantaneous observation of the form (t_i, y_i), where t_i is the time of the observation and y_i is the set of values observed for a set of attributes $\boldsymbol{A} = \{ a_1, \ldots, a_p \}$.	$\mathbf{\Omega} = \{ \omega_1, \ldots, \omega_m \}$	Bob adds a problem description to case #123 using the ticketing system.
Time (t)	Timestamp on each occurrence	$t_1 \le t_2 \le \ldots \le t_m$	*11:38 AM*
Threads (**Θ**)	Each thread, θ_i, is a set of occurrences, $\theta_i = \{ \omega_1, \ldots, \omega_r \}$ which all pertain to a single coherent flow of action.	$\mathbf{\Theta} = \{ \theta_1, \ldots, \theta_k \}$	Sequence of all occurrences associated with case #123
Events (***V***)	Each event, υ_i, is a set of occurrences that have the same observed values for a given set of attributes $\boldsymbol{B} \subseteq \boldsymbol{A}$. Events are vertices in a valued, directed graph, **G**.	$\boldsymbol{V} = \{ \upsilon_1, \ldots, \upsilon_n \}$	Set of all the things Bob has done, or of all the tasks involving Microsoft Word.
Edges (**E**)	Each edge, ε_j is indicated by the presence of one or more threads that extend between two events.	$\boldsymbol{E} = \{ \varepsilon_1, \ldots, \varepsilon_s \}$	The sequential relation between any two events
Event network (**G**)	A valued, directed graph, $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$, comprising a set $\boldsymbol{V}$ of events together with a set $\boldsymbol{E}$ of edges	$\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$	

Software Artifact and Empirical Illustration

Using MATLAB, we have implemented an algorithm for converting digital trace data into an event network, as defined in Table 1. It computes the network graph and displays it using the MATLAB Biograph viewer. It also exports an XML file in GEXF format, which contains lists of vertices, edges, and their attributes. This allows for statistical analysis and further processing. Details of the algorithm are omitted to conserve space but are available from the lead author upon request.

Illustration: Problem resolution at a financial services call center

To illustrate the concept of an affordance network, we use data collected for prior study (Pentland 2003) to illustrate each type of event network. The description of the site and data collection methodology is adapted from that earlier publication, in shortened form.

Site description. The Investigations Unit of the U.S. Citibanking Center is responsible for resolving the inquiries and problems of banking customers that cannot be resolved by branch office personnel or the regular call center staff. The Investigations unit handles nearly 30,000 investigations in a typical month, on average. In this paper, for purposes of illustration, we focus on two types of problems.

Method. The data analyzed here include work sequences that were captured on log sheets by staff members of the Investigations Unit as they did their work. The sample was basically a "time slice" of all cases that came into each sub-unit in a given time period. For each case in that sample, the staff member handling the case recorded their actions on special log sheets. Each time the case was handed off to another staff member, a new log sheet was attached and the sequence of actions was continued. The staff members were asked to record what action they took and also what "screen" or system they used to do it. Thus, the raw data includes the {actor-action-artifact} 3-tuple needed to describe each actualized affordance. This method is highly intrusive, so data collection was limited to a small number of days.

The handwritten log sheets were coded for analysis. Each actor and action was given an integer code. Names of systems were retained in text format (e.g., "CitiSmart", etc.) For simplicity, time stamps were replaced with sequence numbers (clock time was replaced with event time). Table 2 shows some example data, which includes the sequence of occurrences for one instance of problem A.

Table 2: Example sequential data

caseID	seqNo	Actor	Action	Artifact
92870330	1	159152	1	Venice
92870330	2	50184434	29	FILM
92870330	3	50184434	29	FILM
92870330	4	50184434	24	Venice
92870330	5	50184434	21	Venice
92870330	6	50184434	21	Venice
92870330	7	50184434	10	Venice
92870330	8	259152	7	CitiSmart

For purposes of illustration, we compare two types of problems carried out by two different, specialized sub-units within the call center. The data contained 20 instances of problem A (with 4.35 occurrences per problem instance) and 29 instances of problem B (with 6.06 occurrences per problem instance). Actors and actions were coded as integers, while the artifacts were described using names (e.g., "Venice").

Figure 1 contains four different views of the same data for each type of problem. The first row in Figure 1 shows the network that results from defining vertices by the types of actions. This view could be called an "action network" (Pentland et al. 2011), and is closest to a traditional process model, either created or mined (van der Aalst 2011a). This view indicates hand-offs between process steps, which is one dimension of interdependence. The second row in Figure 1 shows the network that results from defining vertices by the individual actors. This view can be interpreted as a social network. In this view, the two types of problems are strikingly different. For problem A, one actor initiates every problem, assigns it to someone to resolve, and one actor closes every problem. For problem B, work is passed back and forth, indicating reciprocal interdependence between some actors. The third row in Figure 1 shows a network of artifacts. In this view, we see that work is frequently passed back and forth between the systems, indicating reciprocal interdependence between systems.

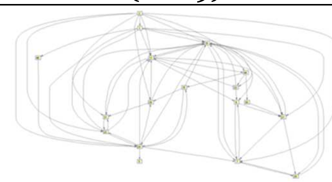
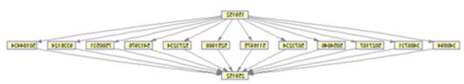
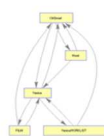
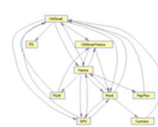
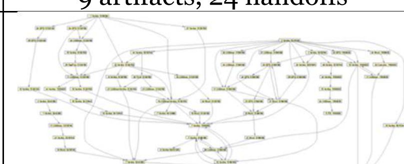
Nodes	**Problem A (n = 20)**	**Problem B (n=29)**
Actions	 11 actions, 22 handoffs	 18 actions, 63 handoffs
Actors	 14 actors, 24 handoffs	 12 actors, 23 handoffs
Artifacts	 5 artifacts, 11 handoffs	 9 artifacts, 24 handoffs
Actualized Affordances	 33 actualized affordances 67 edges; 2.25 handoffs/edge	 62 actualized affordances 106 edges; 1.95 handoffs/edge

Figure 1: Comparing the interdependence structure of two problems

Each view tends to obscure the interdependence that may arise from the other dimensions. To overcome this problem, we represent the workflow as a network of affordances (as in the last row of Figure 1). By increasing the granularity of the description to include the (actor, artifact, action) 3-tuple, this representation reflects interdependence across all three dimensions. Reciprocal relations between actors or artifacts become more clearly articulated as sequences of actualized affordances, and for these routines, the pattern of interdependence can be reduced almost entirely to sequential flow.

Handoffs are a simple indicator of interdependence between actors, actions or systems and have been used in prior measures of interdependence (Bailey et al, 2010; Carroll, Williams and Gallivan 2012). Thus, we examine each edge in the affordance network to determine how many handoffs are involved. Within the network of affordances, each dimension of the 3-tuple (actor, artifact, action) can potentially contribute to the interdependence. For example, if an edge represents two handoffs it means the affordance triple for node 1 differs in two slots from affordance triple in node 2 on the edge. The smallest number of handoffs would be 0: this would be a pure iteration (same actor, same action, same artifact). The maximum number of handoffs would be 3 (new actor, new activity, new artifact). By counting the number of handoffs per edge, we get an index of the overall level of interdependence in the network. While problem A appears to have fewer handoffs then problem B on most dimensions, it has more handoffs per edge overall. Thus, throughout the affordance network, the workflow for problem A may require greater coordination (to manage the higher average level of interdependence).

On-going Work: Using Affordance Networks for Theory Building

So far, we have focused on constructing an affordance network viewer and exploring its application to illustrative empirical examples. Our contribution so far could be understood as what Gregor (2006) calls a Type 1 theory, which is limited to description and analysis. We view this as the generative, theory-building phase of our research. As we continue our experiments with this "interdependence thermometer," a key issue will be how to interpret the results. We envision at least two key advantages. First, since we use digital trace data, the method should be less prone to subjective bias than existing methods based on perceptual survey measures. We intend to explore new visualizations and metrics, so that the relative contribution of each dimension can be seen. Second, it allows us to measure interdependence among any set of entities, not just between pairs of entities. By counting edges that cross boundaries between regions of the graph, we can measure interdependence between heterogeneous entities. Thus, we hope to extend the rigor and applicability of this central concept.

The key contributions of our research-in-progress are methodological and conceptual. Research on socio-technical systems in general and information systems in particular has long been concerned with incorporating actors and artifacts on an equal footing. The affordance network accomplishes this in a simple, intuitive way. We are just beginning to learn how to interpret and analyze these networks, but our "interdependence thermometer" seems likely to facilitate a variety of methodological contributions:

1) Multiple views: examining data about actors and actions as well as artifacts in one model;
2) Nesting: Extending models of single or shared affordances to flows of nested actualized affordances, that is, affordances in sequential combination (Ye et al. 2009);
3) Forensic analysis: tracing evolutionary changes to business processes over time through changes to actors, actions and/or artifacts.

Conceptually, the technique reported here provides a number of promising theory building opportunities.

1) Computing an index of interdependence that is not limited to actions or actors, and that puts heterogeneous actors on an equal footing;
2) Computing an index of task complexity for tasks carried out by multiple actors (human and otherwise). Haerem et al. (2015) have proposed a conceptual approach based on counting pathways in an affordance network. The technique described here makes it possible to construct such a network from digital trace data;
3) Understanding dynamic relationships between the dimensions (social, technical and action). This will especially contribute to affordance theory, by being able to visualize and measure the relational nature of affordances and their actualization over the course of a routine.

Limitations of our research are as follows. Conceptually, our model of an affordance as the tuple (actor, artifact, action) is restricted to an actualized affordance. Thereby, it does not capture affordances that were (a) perceived but not actualized or (b) not perceived in the first place (Chemero 2003). Methodologically, the design of our network viewer is at present restricted to reading and visualizing data. Computations of applicable network statistics such as centrality or entropy are not yet included but can be added. Empirically, we have so far considered data from one set of routines. The case we consider has fairly well-defined tasks within an organizational container (Winter et al. 2014). Different types of routines exist, from highly formalized processes such as invoice processing (Pentland et al. 2010) to highly generative and unstructured routines such as behaviors on online social networks (Kane et al. 2014). It will be interesting to compare interdependencies in affordance networks across cases of formalized versus generative routines or within versus across organizations.

Acknowledgements

We wish to thank Yu Lucy Han for writing the prototype software.

References

Abbott, A. 1992. "From Causes to Events: Notes on Narrative Positivism", *Sociological Methods and Research* (20:4), pp. 428-455.

Alter, S. 2014. "Theory of Workarounds", *Communications of the Association for Information Systems* (34:55), pp. 1041-1066.

Arthur Jr., W., Edwards, B.D., Bell, S.T., Villado, A.J., and Bennett Jr., W. 2005. "Team Task Analysis: Identifying Tasks and Jobs That Are Team Based", *Human Factors* (47:3), pp. 654-669.

Backstrom, L., Sun, E., and Marlow, C. 2010. "Find Me If You Can: Improving Geographical Prediction with Social and Spatial Proximity", in: *19th International Conference on World Wide Web*, ACM, Raleigh, North Carolina, pp. 61-70.

Bailey, D.E., Leonardi, P.M., and Chong, J. 2010. "Minding the Gaps: Understanding Technology Interdependence and Coordination in Knowledge Work", *Organization Science* (21:3), pp. 713-730.

Barabási, A.-L. and Albert, R. 1999. "Emergence of Scaling in Random Networks", *Science* (286:5439), pp. 509-512.

Bernhard, E., Recker, J., and Burton-Jones, A. 2013. "Understanding the Actualization of Affordances: A Study in the Process Modeling Context", in: *34th International Conference on Information Systems,* Baskerville, R. and Chau, M. (eds.), Association for Information Systems, Milan, Italy.

Borgatti, S.P., Everett, M.G., and Johnson, J.C. 2013. *Analyzing Social Networks*, Sage, Los Angeles, California.

Burton-Jones, A. and Weber, R. 2014. "Building Conceptual Modeling on the Foundation of Ontology", in: *Computing Handbook, Third Edition: Information Systems and Information Technology,* Topi, H. and Tucker, A. (eds.), CRC Press, Boca Raton, Florida, pp. 15-1-15-24.

Campion, M.A., Medsker, G.J., and Higgs, A.C. 1993. "Relations between Workgroup Characteristics and Effectiveness: Implications for Designing Effective Work Groups", *Personnel Psychology* (46:4), pp. 823-850.

Carroll, J. S., Williams, M., and Gallivan, T. M. 2012. The ins and outs of change of shift handoffs between nurses: a communication challenge. *BMJ quality & safety* (*21*:7), pp. 586-593.

Chemero, A. 2003. "An Outline of a Theory of Affordances", *Ecological Psychology* (15:2), pp. 181-195.

Curtis, B., Kellner, M.I., and Over, J. 1992. "Process Modeling", *Communications of the ACM* (35:9), pp. 75-90.

Dean, D.L., Lee, J.D., Orwig, R.E., and Vogel, D.R. 2001. "Technological Support for Group Process Modeling", *Journal of Management Information Systems* (11:3), pp. 43-63.

Dumas, M., van der Aalst, W.M.P., and ter Hofstede, A.H.M. (eds.) 2005. *Process Aware Information Systems: Bridging People and Software Through Process Technology*. John Wiley & Sons, Hoboken, New Jersey.

Ellison, N.B., Steinfield, C.W., and Lampe, C. 2007. "The Benefits of Facebook Friends: Social Capital and College Students' Use of Online Social Network Sites", *Journal of Computer-Mediated Communication* (12:4), pp. 1143-1168.

Eppinger, S.D. 1991. "Model-based Approaches to Managing Concurrent Engineering", *Journal of Engineering Design* (2:4), pp. 283-290.

Feldman, M.S. and Pentland, B.T. 2003. "Reconceptualizing Organizational Routines as a Source of Flexibility and Change", *Administrative Science Quarterly* (48:1), pp. 94-118.

Goh, J.M., Gao, G., and Agarwal, R. 2011. "Evolving Work Routines: The Adaptive Routinization of Technology in Healthcare", *Information Systems Research* (22:3), pp. 565-585.

Gregor, S. 2006. "The Nature of Theory in Information Systems", *MIS Quarterly* (30:3), pp. 611-642.

Hayes, G.R., Lee, C.P., and Dourish, P. 2011. "Organizational Routines, Innovation, and Flexibility: The Application of Narrative Networks to Dynamic Workflow", *International Journal of Medical Informatics* (80:8), pp. e161-e177.

Kane, G.C. and Alavi, M. 2008. "Casting the Net: A Multimodal Network Perspective on User-System Interactions", *Information Systems Research* (19:3), pp. 253-272.

Kane, G.C., Alavi, M., Labianca, G., and Borgatti, S.B. 2014. "What's Different about Social Media Networks? A Framework and Research Agenda", *MIS Quarterly* (38:1), pp. 274-304.

Kiggundu, M.N. 1981. "Task Interdependence and the Theory of Job Design", *Academy of Management Review* (6:3), pp. 499-508.

Knights, D. and Willmott, H. 2010. *Organizational Analysis: Essential Readings*, Cengage Learning EMEA, London, England.

Kossinets, G. and Watts, D.J. 2006. "Empirical Analysis of an Evolving Social Network", *Science* (311:5757), pp. 88-90.

Latour, B. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*, Open University Press, Milton Keynes.

Lee, J., Wyner, G.M., and Pentland, B.T. 2008. "Process Grammar as a Tool for Business Process Design", *MIS Quarterly* (32:4), pp. 757-778.

Leonardi, P.M. 2011. "When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies", *MIS Quarterly* (35:1), pp. 147-167.

Leonardi, P.M. 2013. "Theoretical Foundations for the Study of Sociomateriality", *Information and Organization* (23:2), pp. 59-76.

Leonardi, P.M. and Barley, S.R. 2008. "Materiality and Change: Challenges to Building Better Theory about Technology and Organizing", *Information and Organization* (18:3), pp. 159-176.

Malone, T.W., Crowston, K., Lee, J., Pentland, B.T., Dellarocas, C., Wyner, G., Quimby, J., Osborn, C.S., Bernstein, A., Herman, G.A., Klein, M., and O'Donnell, E. 1999. "Tools for Inventing Organizations: Toward a Handbook of Organizational Processes", *Management Science* (45:3), pp. 425-443.

Orlikowski, W.J. 1992. "The Duality of Technology: Rethinking the Concept of Technology in Organizations", *Organization Science* (3:3), pp. 398-427.

Orlikowski, W.J. 2007. "Sociomaterial Practices: Exploring Technology at Work", *Organization Studies* (28:9), pp. 1435-1148.

Orlikowski, W.J. and Scott, S.V. 2008. "Sociomateriality: Challenging the Separation of Technology, Work and Organization", *The Academy of Management Annals* (2:1), pp. 433-474.

Pentland, B.T. 2003. "Sequential variety in work processes", *Organization Science* (14:5), pp. 528-540.

Pentland, B.T. and Feldman, M.S. 2007. "Narrative Networks: Patterns of Technology and Organization", *Organization Science* (18:5), pp. 781-795.

Pentland, B.T. and Feldman, M.S. 2008. "Designing Routines: On the Folly of Designing Artifacts, While Hoping for Patterns of Actions", *Information and Organization* (18:4), pp. 235-250.

Pentland, B.T., Feldman, M.S., Becker, M.C., and Liu, P. 2012. "Dynamics of Organizational Routines: A Generative Model", *Journal of Management Studies* (49:8), pp. 1484-1508.

Pentland, B.T., Hærem, T., and Hillison, D. 2011. "The (N)Ever-Changing World: Stability and Change in Organizational Routines", *Organization Science* (22:6), pp. 1369-1383.

Pentland, B.T., Haerem, T., and Hillison, D. 2010. "Comparing Organizational Routines as Recurrent Patterns of Action", *Organization Studies* (31:7), pp. 917-940.

Polyvyanyy, A., La Rosa, M., Ouyang, C., and ter Hofstede, A.H.M. 2015. "Untanglings: A Novel Approach to Analyzing Concurrent Systems", *Formal Aspects of Computing*, In Press.

Puranam, P., Raveendran, M., and Knudsen, T. 2012. "Organization Design: The Epistemic Interdependence Perspective", *Academy of Management Review* (37:3), pp. 419-440.

Seidel, S., Recker, J., and vom Brocke, J. 2013. "Sensemaking and Sustainable Practicing: Functional Affordances of Information Systems in Green Transformations", *MIS Quarterly* (37:4), pp. 1275-1299.

Sharp, A. and McDermott, P. 2009. *Workflow Modeling: Tools for Process Improvement and Application Development*, (2nd edition ed.), Artech House, Norwood, Massachusetts.

Strong, D.M., Volkoff, O., Johnson, S.A., Pelletier, L.R., Bar-On, I., Tulu, B., Kashya, N., Trudel, J., and Garber, L. 2014. "A Theory of Clinic-EHR Affordance Actualization", *Journal of the Association for Information Systems* (15:2), pp. 53-85.

Thompson, J.D. 1967. *Organizations in Action*, McGraw-Hill, New York, New York.

van der Aalst, W.M.P. 1998. "The Application of Petri Nets to Workflow Management", *The Journal of Circuits, Systems and Computers* (8:1), pp. 21-66.

van der Aalst, W.M.P. 2011a. "Process Mining: Discovering and Improving Spaghetti and Lasagna Processes ", in: *2011 IEEE Symposium on Computational Intelligence and Data Mining*, IEEE, Paris, France.

van der Aalst, W.M.P. 2011b. *Process Mining: Discovery, Conformance and Enhancement of Business Processes*, Springer, Heidelberg, Germany.

van der Aalst, W.M.P., Weijters, A.J.M.M., and Maruster, L. 2004. "Workflow Mining: Discovering Process Models from Event Logs", *IEEE Transactions on Knowledge and Data Engineering* (16:9), pp. 1128-1142.

vom Brocke, J. and Rosemann, M. (eds.) 2010. *Handbook on Business Process Management 1: Introduction, Methods and Information Systems*. Springer, Berlin, Germany.

Winter, S., Berente, N., Howison, J., and Butler, B.S. 2014. "Beyond the Organizational 'Container': Conceptualizing 21st Century Sociotechnical Work", *Information and Organization* (24:4), pp. 250-269.

Wyner, G.M. 2011. "Why Grandma Trims the Brisket: Resource Flows as a Source of Insight for IT-Enabled Business Process Design", in: *Service-Oriented Perspectives in Design Science Research - DESRIST 2011,* Jain, H., Sinha, A.P. and Vitharana, P. (eds.), Springer, Milwaukee, Wisconsin, pp. 398-411.

Ye, L., Cardwell, W., and Mark, L.S. 2009. "Perceiving Multiple Affordances for Objects", *Ecological Psychology* (21:3), pp. 185-217.

Yeow, A. and Faraj, S. 2011. "Using Narrative Networks to Study Enterprise Systems and Organizational Change", *International Journal of Accounting Information Systems* (12:2), pp. 116-125.